

Biodiversity of fruit flies (Diptera, Tephritidae) in orchards in different agro-ecological zones of the Morogoro region, Tanzania

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Biodiversity of fruit flies (Diptera, Tephritidae) in orchards in different agro-ecological zones of the Morogoro region, Tanzania.

Abstract — Introduction. Fruit flies (Diptera, Tephritidae) are among the major constraints in commercial horticulture in many African developing countries. Knowledge of the tephritid spectrum in any given area is a prerequisite for the development of an IPM program to alleviate the pest problem. We studied the fruit fly diversity in four main agro-ecological zones which are significant fruit-producing areas in the Morogoro Region, Tanzania. **Materials and methods.** Fruit fly diversity was investigated for one year (October 2004 – October 2005). Parapheromones, synthetic food attractant and protein-bait traps were used to trap the flies at the different locations in Morogoro region, Tanzania. One mixed orchard was selected at each of four locations representing the different agro-ecological zones of the region. **Results.** The recently introduced alien species, *Bactrocera invadens*, and three indigenous pest species, *Ceratitits rosa*, *Dacus bivittatus* and *D. punctatifrons*, were found at all the four sites, while *Bactrocera cucurbitae*, *Ceratitits cosyra*, *Dacus chiwira* and *D. humeralis* were found in three out of the four sites. The Sokoine University of Agriculture (SUA) Horticulture Unit and Mikese sites had the highest species diversity while the Mkindo and Nyandira sites had the lowest diversity. The between-habitats diversity (Beta diversity) was similar among the SUA, Mkindo and Mikese sites. Only the Nyandira site had a higher dissimilarity in comparison with the other three sites. **Discussion.** The most abundant species at low- and mid-elevation sites was *Bactrocera invadens* while, at high elevation, *Ceratitits rosa* was the dominant species. Protein-baited traps attracted the highest diversity of fruit flies in comparison with the more specific parapheromones. The synthetic food attractant (three-component lure) was less efficient compared with the protein bait. The large dissimilarity at the Nyandira site is probably due to the different types of host fruits found and grown in high altitude areas (mainly temperate fruits). Fruit fly species associated with these types of fruits, e.g., *Ceratitits rubivora* and *Triribthrum coffeae*, were found only at this site.

Tanzania / fruit trees / Tephritidae / fruit flies / biodiversity / Ceratitits / Bactrocera / Dacus / surveys / traps / identification

Biodiversité des mouches des fruits (Diptera, Tephritidae) en vergers, dans différentes zones agro-écologiques de la région de Morogoro, Tanzanie.

Résumé — Introduction. Les mouches des fruits (Diptera, Tephritidae) font partie des principales contraintes de l'horticulture commerciale dans de nombreux pays africains en voie de développement. La connaissance du spectre des tephritides dans un secteur donné est un préalable au développement d'un programme d'IPM permettant d'atténuer le problème parasitaire. Nous avons étudié la diversité des mouches des fruits dans quatre principales zones agro-écologiques qui sont des zones de production fruitière significative dans la région de Morogoro, Tanzanie. **Matériel et méthodes.** La diversité des mouches des fruits a été étudiée pendant une année (octobre 2004 à octobre 2005). Des pièges à paraphéromones, attractifs alimentaires synthétiques et appâts protéinés ont été utilisés pour attraper les mouches dans différents endroits de la région de Morogoro. Un verger composite a été choisi pour chacun des quatre lieux représentatifs des différentes zones agro-écologiques de la région. **Résultats.** L'espèce étrangère *Bactrocera invadens*, récemment introduite, et trois espèces nuisibles indigènes, *Ceratitits rosa*, *Dacus bivittatus* et *D. punctatifrons*, ont été trouvées aux quatre emplacements prospectés, alors que *Bactrocera cucurbitae*, *Ceratitits cosyra*, *Dacus chiwira* et *D. humeralis* étaient identifiées dans trois emplacements sur les quatre visités. Les sites de l'université d'horticulture et d'agriculture de Sokoine (SUA) et de Mikese ont montré la diversité d'espèces la plus élevée tandis que les localités de Mkindo et de Nyandira révélaient une plus basse diversité. La diversité intra-habitats (bêta diversité) a été la même pour les sites de SUA, Mkindo et Mikese. Seule la localité de Nyandira a révélé une dissimilitude plus importante que celle des trois autres localisations. **Discussion.** L'espèce la plus abondante à basse et moyenne altitudes a été *Bactrocera invadens*, alors que, à altitude élevée, *Ceratitits rosa* a été l'espèce dominante. Les pièges avec appât protéiné ont attiré la plus forte diversité de mouches des fruits par rapport aux paraphéromones plus spécifiques. L'attractif alimentaire synthétique (appât à trois composants) a été moins efficace comparé à l'appât protéiné. La grande dissimilitude observée à Nyandira est probablement due aux différents types de fruits hôtes trouvés et cultivés dans ce lieu d'altitude élevée, fruits d'espèces tempérées principalement. Des espèces de mouches des fruits associées à ces types de fruits, *Ceratitits rubivora* et *Triribthrum coffeae*, par exemple, n'ont été trouvées qu'à cet emplacement.

Tanzanie / arbre fruitier / Tephritidae / mouche des fruits / biodiversité / Ceratitits / Bactrocera / Dacus / enquête / piège / identification

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RESUMEN ESPAÑOL, p. 332

1. Introduction

The Sub-Saharan African region is a growing center for tropical and subtropical fruit production and export. Its capacity is still relatively small, compared with South American or Asian markets, but it has been growing considerably in the past few years¹. In addition, fruits supply an essential addition to local nutrition and generate income in these countries. For several tropical fruits, the production is mainly by smallholder producers largely intended for local consumption in the rapidly expanding local urban markets [1]. Tanzania's agro-based economy could be boosted by finding reliable markets for its non-traditional export crops such as fruits. However, reliable markets for fruits can be secured only when a country is able to produce high quality fruits, free from pests and diseases. Production of high quality fruits in Tanzania is hampered by economic and developmental constraints, but also by insect pests, especially fruit flies (Diptera: Tephritidae). Infestation by the latter is a major constraint to the local fruit production, e.g., losses of up to 40% are attributed to this in mangoes alone in East Africa [1]. The damage to fleshy fruits is probably mainly caused by a limited number of highly polyphagous species.

The status of fruit fly research in Tanzania has recently been reviewed [2]. It is shown that little has been done to study fruit flies in the country, especially to establish the quantitative and qualitative losses they cause in fruits. So far, there is no proper management program of fruit flies that has been formulated for smallholder farmers in Tanzania. Moreover, the situation has been worsened with the introduction into the country of the invasive fruit pest species *Bactrocera invadens* [3]. *Bactrocera invadens* occurs in large numbers and causes heavy losses in fruits, especially mangoes. In the country, Morogoro region is among the major fruit-producing areas. Both temperate and tropical fruits are produced in this agro-ecologically diverse region and most of these are attacked by different species of fruit flies. The losses are undoubtedly high, although they have not

been reliably quantified. In order to alleviate the situation, there is a need to formulate an ecologically-based Integrated Pest Management (IPM) program for fruit flies, because such programs are normally environmentally sustainable and economically affordable to smallholder farmers [4]. Fruits produced in such systems, which entail minimal or no use of pesticides, are of high quality, satisfying the minimum residue limits imposed on exporting countries.

Two of the important requirements for formulating an IPM program are to establish the diversity of the local fruit fly fauna and to determine parameters necessary for its formulation, including the population ecology of the involved species. Our paper reports on the diversity of fruit flies in Morogoro region, Tanzania, based on a one-year trapping program. The alpha diversity (species richness or within-habitat diversity [5]) and beta diversity (differentiation diversity or between-habitats diversity [5]) at the different sites are analyzed. The study also compares the efficiency of lures at capturing the fruit flies at the different sites.

2. Materials and methods

2.1. Study sites

Surveys were conducted between September and October 2004 to select the experimental sites in the agro-ecological zones of Morogoro region. A total of four sites were selected (*figure 1*), including Sokoine University of Agriculture (SUA) Horticulture Unit (Morogoro urban District), a demonstration orchard in Nyandira-Tchenzema ward (Mvomero District), a commercial orchard in Mikese ward (Morogoro rural District) and a smallholder orchard in Mkindo ward (Mvomero District). The selection was based on agro-ecological characteristics and fruit production. Each site was characterized with an indication of geographical position, size and fruit varieties present (*table I, II*). Wild fruits (including cucurbits) growing in and around the different selected orchards were observed, but their inventory and identification was outside the scope of this research.

¹ <http://apps.fao.org/>

2.2. Trapping

Trapping was conducted for one full year's cycle from mid-October 2004 to mid-October 2005. The focus was on fruit-infesting species, mainly Ceratitid fruit flies, in particular the genera *Ceratitis* and *Triribthrum*. The Dacine fauna, with special emphasis on *B. invadens* and some of the major cucurbit-infesting species, was also studied.

Modified McPhail traps baited with different types of lures (all purchased from Scentry, Montana, USA) were used. Trimed-lure was used to attract members of the genus *Ceratitis*, sub-genera *Ceratitis* and *Pterandus*. Methyl eugenol was used to attract members of the genus *Ceratitis* sub-genus *Pardalaspis*, as well as the invasive *B. invadens*. Cue Lure was used to attract members of *Dacus* and *Bactrocera cucurbitae*. An insecticide strip of dichlorovos (vapon) was placed in each trap to kill the adult flies. In addition, protein bait and single matrix synthetic food attractant (three-component lure, containing putrescine, ammonium acetate and trimethylamine) (also from Scentry Cie), which are less specific than the above mentioned lures, were also used to attract other fruit flies.

At SUA, two replicates for each bait type were put up in the mango (varieties 'Sindano Nyeusi' and 'Dodo') part, the same two replicates were put in the citrus (varieties 'Tahiti lime' and 'Sweet seedling') part, and one replicate in the guava (unknown variety) part of the orchard. In Mikese, four replicates (all under mango trees: varieties 'Tommy atkins', 'Maya', 'Red Indian' and 'Alphonso') while, at the other two sites, two replicates, also for each bait type, were set. In Mkindo, the baits were set under citrus trees of unknown variety, and, in Nyandira, under a peach tree of unknown variety and a plum tree of the variety 'Santa Rosa'. At all sites, the traps were hung on selected trees, placed 1.5–2 m above the ground. All the five traps were hung on the same tree and rotated clockwise after each emptying.

Traps were inspected and catches were collected once a week at the SUA Horticulture Unit, while lures and insecticide strips

were changed at the end of every fourth week. The protein bait was replaced once a week. Flies were collected once a month in all the other stations. At these sites, lures and protein baits were placed every third week and left to stay for one week. After that, the lures were removed and discarded. Fruit flies were collected and placed into vials containing alcohol for preservation, labeled and transported to the laboratory for identification and counting.

Figure 1. Location of four sites (indicated by stars) studied within Morogoro Region (Tanzania) to identify the biodiversity of fruit flies in orchards.

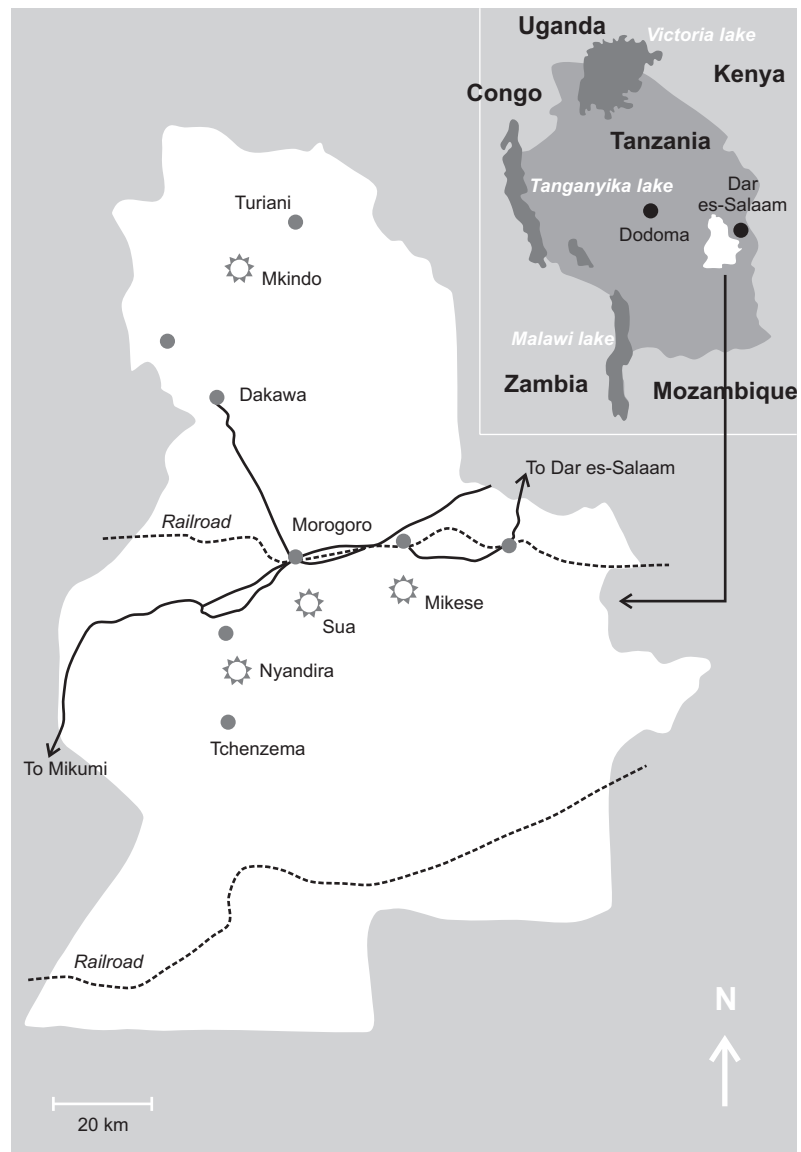


Table I.

Characteristics of the sites in Morogoro Region (Tanzania), studied to identify the biodiversity of fruit flies in orchards.

Location	Description of the area	Fruits cultivated (common name and scientific name)
Sokoine Univ. Agric. (SUA): Lat. 06° 50' – 06° 45' S Long. 37° 35' – 37° 40' E Alt. 520 m Plateau zone	15 ha A research, demonstration and semi-commercial horticulture unit	– Mango, <i>Mangifera indica</i> L.; tangerine, <i>Citrus reticulata</i> Blanco; lemon, <i>Citrus limon</i> (L.) Burman f.; sweet orange, <i>Citrus sinensis</i> (L.) Osbeck. – Also breadfruit, <i>Artocarpus altilis</i> (Parkins.) Fosb.; avocado, <i>Persea americana</i> Miller.; governors' plum, <i>Flacourtia indica</i> (Burman f.) Merr.; guava, <i>Psidium guajava</i> L.; grapefruit, <i>Citrus paradisi</i> Macfad.; soursop, <i>Annona muricata</i> L.; cherimoya, <i>Annona cherimola</i> Miller; pomelo, <i>Citrus grandis</i> (Burman) Merr.; star fruit, <i>Averrhoa carambola</i> L.; grapes, <i>Vitis vinifera</i> L.; passion fruit, <i>Passiflora edulis</i> f.s. <i>flavicarpa</i> ; loquat, <i>Eriobotrya japonica</i> (Thunb.) Lindley; kumquat, <i>Fortunella margarita</i> (Thunb.) Swingle; jackfruit, <i>Artocarpus heterophyllus</i> Lam.; pawpaw, <i>Carica papaya</i> L.; and jew plum, <i>Spondias cytherea</i> Sonn occur. – In addition, different vegetable crops are grown, including cucurbits such as cucumber, <i>Cucumis sativus</i> L. (table II lists all varieties grown here).
Mikese: Lat. 06° 46' – 06° 46' S Long. 37° 55' – 37° 55' E Alt. 390 m Plateau zone	8.6 ha A small commercial orchard	– Mango (varieties Maya, Red India, Kent, Tommy atkins), sweet orange, pawpaw and avocado. – Watermelon, <i>Citrullus lanatus</i> (L.) (grown in neighboring farms).
Mkindo: Lat. 06° 14' – 06° 14' S Long. 37° 33' – 37° 33' E Alt. 380 m River valleys and basin zone	1.3 ha A smallholder orchard	– Sweet orange, lemon, mango, guava and coconut, <i>Cocos nucifera</i> L.
Nyandira: Lat. 7° 05' – 7° 00' S Long. 37° 30' – 37° 35' E Alt. 1650 m Mountainous area	2 ha A demonstration orchard	– Mainly temperate fruits are grown. Fruits grown in the orchard include apple, <i>Malus</i> spp.; peach, <i>Prunus persica</i> (L.) Batsch.; plum, <i>Prunus salicina</i> Lindley; strawberry, <i>Fragaria</i> spp.; coffee, <i>Coffea canephora</i> Pierre ex A. Froehner; feijoa, <i>Feijoa sellowiana</i> (O. Berg) O. Berg.; guava, <i>Psidium</i> spp.; nectarines, <i>Prunus persica</i> (L.) Batsch; loquat, cherimoya and avocado.

Table II.

Inventory of fruit varieties grown at Sokoine University of Agriculture (SUA) Horticulture Unit, Morogoro urban District, Tanzania.

Fruits	Varieties
Citrus	– Orange: Valencia late, Early Valencia, Mediterranean sweet, Orlando, Sweet seedling, Hamlin, Pineapple, Casa grande oasis, Parson brown, Marsh early, Dan Joa, Matombo sweet, Binti Juma, Morogoro, Jaffa, Navelencia, Red Blush Ruby, Washington navel, Zanzibar. – Tangerines: Morogoro, Fairchild, Fortune, Dancy, Clementine, King, Kara, Murcott, Tangelo, Mandarin. – Grapefruit: Triumph, Dancan, Marsh seedless. – Lime: Tahiti. – Kumquat: Marumi.
Mango	Red Indian, Tommy Atkins, Kent, Keitt, Maya, Malgoba, Alphonso, Sandersha, Ngowe, Banda, Boribo Muyuni, Boribo Siagi, Boribo Nyekundu, Boribo Pemba, Dodo, Mwaka, Apple, Alizeti.
Guava	Pink, White.

2.3. Identification

Different types of keys were used: recent systematic revisions for *Ceratit* and *Trirhi-*

thrum [6–9] that were also incorporated in an unpublished digital multi-entry key [10]. For the dacines and other fruit flies, several other keys were used [11–13]. For *Dacus*

Table III.

Numbers of insects (both sexes combined) of the different fruit fly species collected at four different study sites in Morogoro Region (Tanzania) (SUA: Sokoine University of Agriculture).

Genus	Species	SUA	Mikese	Mkindo	Nyandira	Total	Percentage
<i>Bactrocera</i>	<i>amplexa</i>	1	–	–	–	1	0.0005
	<i>cucurbitae</i>	1024	468	7	–	1499	0.7841
	<i>invadens</i>	143384	23065	19138	27	185614	97.0866
<i>Dacus</i>	<i>bivittatus</i>	98	50	16	7	171	0.0894
	<i>chiwira</i>	5	13	1	–	19	0.0099
	<i>ciliatus</i>	5	8	–	–	13	0.0068
	<i>durbanensis</i>	5	–	1	–	6	0.0031
	<i>humeralis</i>	137	71	15	–	223	0.1166
	<i>hyalobasis</i>	–	–	–	15	15	0.0078
	<i>katonae</i>	–	1	–	–	1	0.0005
	<i>punctatifrons</i>	194	98	11	4	307	0.1606
	<i>vertebratus</i>	5	8	–	–	13	0.0068
	<i>Ceratitis</i>	<i>aliena</i>	–	–	–	25	25
<i>capitata</i>		62	33	–	–	95	0.0497
<i>cosyra</i>		96	63	2	–	161	0.0842
<i>dumeti</i>		1	–	–	–	1	0.0005
<i>fasciventris</i>		10	–	–	1	11	0.0058
<i>flexuosa</i>		–	1	–	–	1	0.0005
<i>rosa</i>		2204	53	3	701	2961	1.5488
<i>rubivora</i>		–	–	–	41	41	0.0214
<i>dimidiata</i>		–	1	–	–	1	0.0005
<i>Carpophthoromyia</i>	<i>dimidiata</i>	–	1	–	–	1	0.0005
<i>Perilampus</i>	<i>cf. curta</i>	–	1	–	–	1	0.0005
<i>Trirhithrum</i>	<i>coffaeae</i>	–	–	–	4	4	0.0021
Total		147231	23934	19194	825	191184	
Total of species		15	15	9	9	23	

taxa, when in doubt, confirmation of the identification was sought from Dr I. White (Natural History Museum, London, UK). Voucher specimens are kept in collections at the Sokoine University of Agriculture, Tanzania and the Royal Museum for Central Africa, Belgium.

3. Results

3.1. Alpha diversity

In total, over the full year's cycle, 191 184 specimens were collected (table III). Of these, 97.087% belonged to *Bactrocera invadens*, while the second and third most

common species (*Ceratitis rosa* and *Bactrocera cucurbitae*) represented 1.5488% and 0.7841%, respectively. The total number of all remaining fruit flies constituted less than 0.70% of the total catch. The SUA Horticultural Unit and Mikese sites showed the highest diversity, with 15 species found at each site. The Mkindo and Nyandira sites had a much lower diversity, with nine species found at each site. Four species were found in all four sites: *Bactrocera invadens*, *Ceratitis rosa*, *Dacus bivittatus* and *D. punctatifrons*, while *Bactrocera cucurbitae*, *Ceratitis cosyra*, *Dacus chiwira* and *D. humeralis* were found at three out of the four sites. All species were previously reported in Tanzania.

Table IV.

Number of insect catches per different type of trap at four different study sites in Morogoro Region (Tanzania).

Genus	Species	Methyl eugenol	Cue lure	Trimed lure	Protein bait	Three-component lure
Dacina						
<i>Bactrocera</i>	<i>amplexa</i>	–	–	–	1	–
	<i>cucurbitae</i>	–	1170	4	319	6
	<i>invadens</i>	180269	15	62	4944	324
<i>Dacus</i>	<i>bivittatus</i>	–	150	1	20	–
	<i>chiwira</i>	–	19	–	–	–
	<i>ciliatus</i>	–	1	–	9	3
	<i>durbanensis</i>	–	6	–	–	–
	<i>humeralis</i>	–	219	–	4	–
	<i>hyalobasis</i>	–	1	–	14	–
	<i>katonae</i>	–	–	–	1	–
	<i>punctatifrons</i>	1	285	–	21	–
	<i>vertebratus</i>	–	4	–	9	–
	Ceratitidina					
<i>Ceratitis</i>	<i>aliena</i>	–	1	2	21	1
	<i>capitata</i>	–	–	77	10	8
	<i>cosyra</i>	–	–	10	127	24
	<i>dumeti</i>	–	–	–	1	–
	<i>fasciventris</i>	–	–	10	1	–
	<i>flexuosa</i>	–	–	–	1	–
	<i>rosa</i>	12	10	1304	1005	630
	<i>rubivora</i>	–	–	9	26	6
<i>Carpophthoromyia</i>	<i>dimidiata</i>	–	–	–	1	–
<i>Perilampis</i>	<i>cf. curta</i>	–	–	–	1	–
<i>Trirhithrum</i>	<i>coffae</i>	–	–	–	4	–
Total		180282	1881	1479	6540	1002
Total of species		3	12	9	21	8

3.1.1. Major pest species

3.1.1.1. *Bactrocera cucurbitae* (Coquillett)

The melon fruit fly is a widespread pest species of Asian origin. The first African records date back to 1930 [14] and are from Kenya. Recently, it has also been found in western Africa [11]. Most East African records are from cultivated cucurbits such as cucumber (*Cucumis sativus* L.). Among the *Dacus* species attracted to cue lure, *B. cucurbitae* was the most abundant species (table IV).

3.1.1.2. *Bactrocera invadens* Drew, Tsuruta & White

This species has been recorded very recently in Tanzania [3] and Benin [15]. It is an invasive species (probably of Asian ori-

gin) that was introduced into Africa and it is spreading very fast throughout the continent [16]. Similar material, collected in Sri Lanka, was considered conspecific and the species was first described in 2005 [16]. *Bactrocera invadens* belongs to the *B. dorsalis* species complex, which harbors a number of important pest species such as *B. carambolae*, *B. papayae* and *B. kandiensis* [17]. In Africa, it seems to show a great dispersal power, attacking a wide variety of commercial fruit species.

3.1.1.3. *Ceratitis rosa* Karsch / *C. fasciventris* (Bezzi)

Ceratitis rosa or the Natal fruit fly is a major economic pest in southern and eastern Africa. It has been reported in several countries from South Africa northwards to Kenya

[18]. It was also accidentally introduced into the island of Réunion where it largely replaced the equally introduced *C. capitata* [19]. It is a polyphagous species attacking a wide variety of unrelated fruits. So far, it has been reared from close to 100 hosts, belonging to 30 plant families [20]. *Ceratitis fasciventris* was considered a mere variety of *C. rosa*, but was recently ranked as a separate species, based on morphological and genetic studies [21–23]. *Ceratitis fasciventris* and *C. rosa* have a largely allopatric distribution, with *C. fasciventris* in western and Central Africa and occurring sympatrically only at certain sites in Kenya. A limited number of *C. fasciventris* specimens was found at two sites in Morogoro region (Nyandira and SUA), indicating co-existence in these sites.

3.1.1.4. *Dacus bivittatus* (Bigot)

Dacus bivittatus, or the pumpkin fly, is one of the most common and widespread species of the genus *Dacus*. It has been reported in 28 African countries [11] distributed over the whole of the continent. It mainly attacks Cucurbitaceae such as cucumber and melon (*Cucumis melo* L.), but it is also reported from non-cucurbit hosts such as tomato (*Lycopersicon esculentum* Miller, Solanaceae).

3.1.1.5. *Dacus humeralis* (Bezzi) / *D. chiwira* Hancock

Dacus humeralis is found mainly in western and Central Africa, but it has also been recorded in Kenya, Tanzania and Uganda. Unlike most other *Dacus* species found in Morogoro region, for which we have confirmed host associations, *D. humeralis* is not reported from Cucurbitaceae but reared from *Adenia gummifera* (Passifloraceae). It is a variable species that closely resembles *D. chiwira*. Both species were found in the same sites. As indicated by White [11], the species status of both taxa needs to be studied further since the only consistent differentiating character (presence or absence of anterior supra-alar setae) is known to vary in other *Dacus*.

3.1.1.6. *Dacus punctatifrons* Karsch

Dacus punctatifrons is widespread and has been recorded in several African countries,

with a (possible) adventive population in Yemen [24]. It attacks a wide range of Cucurbitaceae [11] but has also been reared from tomato and wild watermelon (*Passiflora foetida*, Passifloraceae).

3.1.2. Minor pests

3.1.2.1. *Ceratitis capitata* (Wiedemann)

Although the Mediterranean fruit fly is often considered the most harmful fruit fly, with an African origin [25] but spread over five continents and close to 400 host plants [20, 26], its presence in the Morogoro region seems to be limited, based on the trapping results. It was only found at two sites (Mikeese and SUA) but never abundantly (table III). Whether this is due to environmental factors unfavorable to the establishment of this species (probably the case in Nyandira because of the colder climate at this high altitude) or a recent phenomenon due to displacement by other polyphagous species such as *Bactrocera invadens* needs to be assessed.

3.1.2.2. *Ceratitis cosyra* (Walker)

The mango fruit fly or marula fruit fly (*C. cosyra*) is a widespread species found throughout the African continent. It is a polyphagous pest, attacking close to 30 different fruit species [20]. It is considered the main fruit fly found in mangoes (*Mangifera indica*, Anacardiaceae), accounting for the major losses in mango production. However, in predominantly mango orchards such as Mikeese and the traps in the mango part of SUA, its occurrence was relatively low (table III).

3.1.2.3. *Ceratitis rubivora* Coquillett

The blackberry fruit fly is found throughout southern and eastern Africa. As the common name already indicates, it is a stenophagous species attacking solely representatives of the genus *Rubus* [20].

3.1.2.4. *Dacus ciliatus* Loew

The lesser pumpkin fly (also known as Ethiopian fruit fly or cucurbit fly [24]) is a widespread species found throughout the African continent as well as the Indian Ocean

Table V.
Diversity indices of the fruit fly populations at the different sites studied in Morogoro Region (Tanzania) (SUA: Sokoine University of Agriculture).

Jaccard index			
Study site	Mkindo	SUA	Nyandira
Mikese	0.500	0.579	0.200
Mkindo	–	0.600	0.286
SUA	–	–	0.263
Sorensen index			
Study site	Mkindo	SUA	Nyandira
Mikese	0.667	0.733	0.333
Mkindo	–	0.750	0.444
SUA	–	–	0.417

islands, Middle East and Oriental Asia [24]. It attacks a wide variety of cucurbit fruits such as several *Cucumis* species, pumpkin (*Cucurbita maxima* Duchesne) and *Momordica* spp. There are also some records from non-cucurbit hosts such as tomato or beans that need confirmation [11]. Morphologically it is a very variable species. The species was present in low numbers in the traps used in this study, and only in the food attraction types.

3.1.2.5. *Dacus vertebratus* Bezzi

The melon fly is also a known pest of cucurbit crops, especially watermelon (*Citrullus lanatus*) and several *Cucumis* spp. [11]. It is found throughout the African continent and the Middle East. According to White [11], this species differs from *D. ciliatus* in usually having the laterotergal xanthine across the anatergite as well as katatergite, which is the case in our specimens. However, some of the specimens were collected in a cue lure trap, which was not expected for the species.

3.1.2.6. *Trirhithrum coffeae* Bezzi

The coffee fruit fly attacks the berries of *Coffea* species (such as *Coffea canephora* Pierre ex Froehner, but also *C. arabica* L. in small numbers) although the infestation does not seem to have a detrimental effect

on coffee production [9]. Its taxonomic position and confusion with other *Trirhithrum* species such as *T. nigerrimum* Bezzi and *T. inscriptum* (Graham) have only recently been clarified [9].

3.1.3. Other fruit flies

Nine other species of fruit flies were collected at the different sites. In most cases, these were single specimens of species of no economic importance, including *Bactrocera amplexa* (Munro), *Dacus katonae* Bezzi, *Carpophthoromyia dimidiata* Bezzi, *Ceratitidis dumeti* Munro, *C. flexuosa* (Walker), and *Perilampus* sp. probably *curta* Munro. *Dacus durbanensis* Munro, *D. hyalobasis* Bezzi and *Ceratitidis aliena* (Bezzi) were occasionally found in relatively low numbers at one or two sites.

3.2. Beta diversity

Beta diversity measures how different or similar habitats or samples are in terms of the variety of species found in them [5]. In this case, the species composition of the different study sites was compared. The results of the different traps are pooled. Only the presence and absence data are used, since the differences in attractiveness of the different lures used do not allow use of quantitative data. The Jaccard and qualitative Sorensen indices were calculated according to the formulae provided by Magurran [5]. These indices are equal to 1 when there is complete similarity and to 0 if the sites have no species in common. In our studies, the highest similarity was observed between SUA, Mkindo and Mikese (*table V*). All these are low-altitude areas (380–520 m). The Nyandira site at high altitude (1650 m) had the lowest indices with respect to all the other sites, indicating that it had quite different species composition.

3.3. Lure response

Parapheromone baits such as methyl eugenol are very specific and only collected a limited number of flies, while protein bait and synthetic food attractant (three-component lure) attracted a much wider spectrum of flies (*table IV*).

4. Discussion

4.1. Pest species composition

Among the dominant species found at all sites studied in the Morogoro region (Tanzania), several species of the genera *Ceratitidis* and *Dacus* were represented. Members of the genus *Ceratitidis*, such as *C. rosa*, *C. capitata* and *C. cosyra*, are known economic pests attacking a wide variety of fleshy fruits. In addition, the invasive *Bactrocera invadens* was prevalent in three of the four sites. Hosts for afro-tropical *Dacus* species appear to belong to three plant families, namely Cucurbitaceae, Passifloraceae and Asclepiadaceae (the latter included nowadays under Apocynaceae) [11]. The phylogenetic relationship between species groups or subgenera recognized within the genus *Dacus* and host utilization was recently studied [11]. The homoplastic nature of the observed host range is, however, not fully clarified. The dominant representatives of the genus *Dacus* that were collected at the study sites are all cucurbit feeders. In general, it can be stated that the major fruit fly pests that occur in Tanzania, as listed by Mwatawala *et al.* [3], were recorded from the study sites in the Morogoro region.

The other species found were usually present in low numbers, often represented by a single specimen (as is the case for *Bactrocera amplexa*, *Carpophthoromyia dimidiata*, *Ceratitidis dumeti*, *C. flexuosa*, *Perilampus cf. curta* and *Dacus katonae*). These species are of no economic importance, and often with stenophagous or monophagous host range among indigenous fruits. *Ceratitidis flexuosa* is sometimes associated with mangoes in western Africa but always in low numbers [20, 27]. Whether it routinely attacks mangoes has still to be confirmed.

SUA is the most diverse site with regard to available hosts with fleshy fruits. Mikese is much less diverse in potential hosts but shows an equally diverse fruit fly fauna. However, a large proportion of the observed Mikese fruit fly fauna was represented by single specimens of species with little or no economic importance. This is therefore more a reflection of the total host availability in the surroundings, including indigenous wild hosts, rather than the fruit fly pest fauna.

4.2. Beta diversity

A large similarity was observed between the three sites at low and medium altitude. Only Nyandira, at high altitude, shows a remarkable dissimilar fauna compared with the other three sites. This is most likely caused by the different range of fruits available at the Nyandira site. These are mainly temperate fruits and crops that need colder conditions, including apple, peach, plum and coffee. Also, a *Rubus* sp. and *Solanum* sp. were observed here during site visits (hosts for, respectively, *Ceratitidis rubivora* and *C. aliena*); they were not observed at the other sites. On the other hand, cucurbit infesters such as *Bactrocera cucurbitae*, *Dacus punctatifrons* or *D. bivittatus* were absent, or present only in comparatively very low numbers. The invasive *Bactrocera invadens*, present in high numbers at the other sites, was found at this site also in relatively very low numbers and only part of the year. Apparently, the climatic conditions present in Nyandira seem to cause a barrier for the establishment of this species at this altitude. This should be tested, however, in experimental settings to test the survival and development of different life stages against a gradient of different temperatures. Similar studies for *C. capitata* and *C. rosa* have shown a higher tolerance of *C. rosa* to low temperatures by lower temperature thresholds in the laboratory [28]. *Bactrocera invadens* may possibly outcompete native polyphagous species such as *Ceratitidis capitata* or *C. rosa* in certain regions, depending on environmental conditions.

4.3. Lure response

Lure response is specific, with each pheromone attracting a subset of species of different genera. In general, the lure response corresponds to published records for the different species. Methyl eugenol (ME) is known to attract *Bactrocera invadens* but none of the other dacines in Africa. In addition, it attracts *Ceratitidis* spp. belonging to the subgenus *Pardalaspis*, but apparently none of these were present at the study sites. Cue lure (CL) is known to attract a number of *Dacus* species, especially in those groups that are associated with Cucurbitaceae or

Passifloraceae. Trimedlure (TM) attracts representatives of the subgenera *Ceratitidis* s.s. and *C. Pterandrus*. The efficiency of each parapheromone is different. For example, ME is known to be very potent and this might be the reason for high numbers of *Bactrocera invadens*. However, field observations and the catches in protein-bait traps do show *B. invadens* as the dominant species in three of the four sites. Only in Nyandira was *Ceratitidis rosa* the dominant species found. Protein bait (PB) and three-component (3C) lure are actually attractants that do not operate as (para)pheromones but as food substances required for proper development of eggs. Therefore, they are more general than the specific parapheromone lures, and their captures might reflect more the proportional presence of the different fruit flies in the particular environments. On the other hand, the radius over which they attract flies is much smaller than that of parapheromones and therefore presents better the fruit fly fauna immediately surrounding the site where a trap is placed, rather than a larger area. PB trap results were the second highest in total number of specimens caught and the highest in number of taxa. All taxa found in the different study sites, except for two (*D. chiwira* and *D. durbanensis*), were captured with PB traps. Compared with the PB trap results, the efficiency of the 3C bait was much lower. This could, however, be due to the fact that the development of the synthetic lure attractant is still at an experimental stage and that the different components are not yet fully optimized (Holler, pers. comm.).

Occasionally aberrant records of specimens were found in lures from which they are usually not recorded. For example, several specimens of *Bactrocera invadens* were found in TM and CL traps (table IV). There was also the occasional *C. rosa* in ME or CL traps, and *Dacus bivittatus* in TM traps. However, this seems to be the result of accidental introductions into these particular traps and most likely does not reflect a true parapheromone response. In general, all known lures for different species are confirmed in this study. Species such as *C. hyalobasis* and *D. ciliatus*, which are known not to be attracted to the parape-

romones used, were either absent or present in very low numbers, in which case they are attributed to accidental entries. *Ceratitidis rubivora* is reported to be attracted to TM [29]. This was also observed in our study, albeit in much lower numbers than, for example, in the protein-bait trap. It could be that TM is only weakly attractive to *C. rubivora*. A few specimens of *D. vertebratus* were collected in CL traps. *D. vertebratus* is usually attracted to vert lure (methyl-4-hydroxybenzoate), while the closely related *D. frontalis* is attracted to CL [11]. Vert lure was not used in our survey and the specimens key out to *C. vertebratus* with regard to diagnostic characters of femur coloration and apical wing spot. There is, therefore, no full correspondence in this study with earlier reports and the matter needs further investigation.

4.4. Impact of *Bactrocera invadens* on indigenous fruit fly diversity

Several of the fruit fly species found in this area belong to the traditional major fruit pests recognized for the region, such as *C. capitata*, *C. cosyra* and *C. rosa*. The relative abundance of these flies, however, seems to be affected by the recently introduced alien *Bactrocera invadens*. It appears that this alien is outcompeting and replacing the indigenous pests, a phenomenon that has been observed repeatedly in fruit fly invasions [19]. Abiotic environmental aspects may have an effect on the occurrence and dominance of the alien species though, as has been observed by the relatively low numbers of *C. capitata* at low altitudes but the dominance of the indigenous *C. rosa* at higher and colder altitudes, where *B. invadens* appears not to be established. Agro-systems at different altitudes have a different species composition and the impact of the alien species differs accordingly. The data so far seem to indicate that *B. invadens* should be considered as a serious pest threatening the horticultural industry in the whole Sub-Saharan region and that it may have a considerable impact on the local fruit fly fauna. A detailed study of its ecology and population dynamics and development of adequate control mechanisms should, therefore, be considered a high priority.

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Biodiversidad de las moscas de la fruta (Diptera, Tephritidae) en vergeles, en diferentes zonas agro-ecológicas de la región de Morogoro, Tanzania.

Resumen — Introducción. Las moscas de la fruta (Diptera, Tephritidae) se encuentran entre los máximos obstáculos de la horticultura comercial en numerosos países africanos en vía de desarrollo. El conocimiento del espectro de los tefritidos en un sector determinado es un prerrequisito para el desarrollo de un programa de IPM, que permita atenuar el problema parasitario. Estudiamos la diversidad de las moscas de la fruta en cuatro zonas principales agro-ecológicas, que son zonas de importante producción fructífera en la región de Morogoro, Tanzania. **Material y métodos.** Se estudió durante un año (desde octubre 2004 hasta octubre 2005) la diversidad de las moscas de la fruta. Con el fin de atrapar las moscas se utilizaron en diferentes lugares de la región de Morogoro unas trampas basadas en paraferomonas, atrayentes alimenticios sintéticos y cebos proteinados. Se eligió un vergel compuesto para cada uno de los cuatro lugares representativos de las diferentes zonas agro-ecológicas de la región. **Resultados.** Se encontraron en los cuatro emplazamientos prospectados la especie extranjera introducida recientemente *Bactrocera invadens*, así como otras tres especies dañinas autóctonas *Ceratitis rosa*, *Dacus bivittatus* y *D. punctatifrons*, mientras que *Bactrocera cucurbitae*, *Ceratitis cosyra*, *Dacus chiwira* y *D. humeralis* fueron encontrados en tres de los cuatro emplazamientos visitados. Los sitios de la universidad de horticultura y de agricultura de Sokoine (SUA) y de Mikese revelaron la diversidad de especies más elevada, mientras que las localidades de Mkindo y de Nyandira mostraron una diversidad más baja. La diversidad intra-habitats (diversidad- β) fue la misma para los sitios de SUA, Mkindo y Mikese. Únicamente la localidad de Nyandira reveló una disimilitud más importante que la de los otros tres emplazamientos. **Discusión.** La especie más abundante en altitudes baja y media fue *Bactrocera invadens*, mientras que, en elevada altitud, *Ceratitis rosa* fue la especie dominante. Las trampas con cebo proteinado atrajeron la diversidad de moscas de la fruta más marcada en relación con las paraferomonas más específicas. El atrayente alimenticio sintético (cebo de tres componentes) fue menos eficaz en comparación con el cebo proteinado. La gran disimilitud observada en Nyandira se debe probablemente a los diferentes tipos de frutos huéspedes encontrados y cultivados en este lugar de elevada altitud, principalmente frutos temperados. Especies de moscas de la fruta asociadas a estos tipos de frutos, por ejemplo, *Ceratitis rubivora* y *Triribithrum coffeae*, se encontraron sólo en este emplazamiento.

Tanzanía / árboles frutales / Tephritidae / mosca de la fruta / biodiversidad / Ceratitis / Bactrocera / Dacus / encuestas / trampas / identificación